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SINGLE-SAMPLE DISCRIMINATION OF DIFFERENT SCHEDULES' REINFORCED INTERRESPONSE TIMES

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Food-deprived rats in Experiment 1 responded to one of two tandem schedules that were, with equal probability, associated with a sample lever. The tandem schedules' initial links were different random-interval schedules. Their values were adjusted to approximate equality in time to completing each tandem schedule's response requirements. The tandem schedules differed in their terminal links: One reinforced short interresponse times; the other reinforced long ones. Tandem-schedule completion presented two comparison levers, one of which was associated with each tandem schedule. Pressing the lever associated with the sample-lever tandem schedule produced a food pellet. Pressing the other produced a blackout. The difference between terminal-link reinforced interresponse times varied across 10-trial blocks within a session. Conditional-discrimination accuracy increased with the size of the temporal difference between terminal-link reinforced interresponse times. In Experiment 2, one tandem schedule was replaced by a random ratio, while the comparison schedule was either a tandem schedule that only reinforced long interresponse times or a random-interval schedule. Again, conditional-discrimination accuracy increased with the temporal difference between the two schedules' reinforced interresponse times. Most rats mastered the discrimination between random ratio and random interval, showing that the interresponse times reinforced by these schedules can serve to discriminate between these schedules.

Key words: interresponse-time reinforcement, random interval, random ratio, variable interval, variable ratio, rats, lever press

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When variable-ratio (VR) and variable-interval (VI) schedules provide the same rate of reinforcement, the response rate to the VR is usually higher than to the VI (e.g., Catania, Matthews, Silverman, & Yohalem, 1977; Ferster & Skinner, 1957, pp. 399–407; Peele, Casey, & Silberberg, 1984). To illustrate this result, consider Peele et al. who recorded the inter-reinforcement intervals (IRIs) generated by pigeons responding to a VR schedule, and then used those IRIs to create VIs to which the pigeons could respond. Averaged across two determinations in Experiment 1 from their report, response rates were 27% higher on the VR than on the VI.

Peele et al. (1984) attributed this VR–VI rate difference to the fact that on VIs, interresponse time (IRT) duration and reinforcer likelihood are correlated, while on VRs they are not. They argued that, compared to VRs, rates on VIs are reduced by the differential reinforcement these VIs provide for longer IRTs. Since this differential reinforcement is not present on VR schedules, a similar outcome does not obtain.

Peele et al.'s (1984) attribution—that the VR–VI rate difference is due to differences in the probability-of-reinforcement feedback functions produced by IRTs on VR and VI schedules—seems sensible enough; nevertheless, a surprising aspect to their findings remains: Why were the VR–VI rate differences so small? Given that the mean IRI on VI approximates 2 min, why did pigeons respond, on average, every 0.7 s to this schedule, only marginally more slowly than to the VR? If responding is controlled solely by IRT reinforcement as Peele et al. suggested, one might expect much lower response rates to the VI because reinforcement likelihoods for IRTs of, say, 7 or 70 s, are far larger than those produced by the 0.7-s IRTs which their pigeons emitted. Why did these subjects respond so rapidly?

An explanation for this outcome has been provided by Silberberg, Warren-Boulton and Asano (1988). They attributed IRT emission on VI schedules to the joint action of two opposed processes. One, based on IRT rein-

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forcement, slows the rate of responding due to the correlation between the duration of an IRT and the probability of reinforcement. However, this rate-lowering relation is opposed by an impulsivity process: Pigeons trade off the higher likelihood of reinforcement that attends waiting to produce a long IRT for the lower probability of reinforcement that follows from short-IRT emission, because short IRTs reinforce sooner than long IRTs. In consequence, VI rates are not as high as those that obtain when IRT reinforcement does not oppose the pursuit of reinforcer immediacy (i.e., on a VR schedule), but they are not as low as might be expected were control by the IRT, probability-of-reinforcement function of the VI, not bridled by pigeons' tendencies toward impulsivity.

Because of the moderate-to-high VI response rates found in Experiment 1 of Peele et al. (1984), the median reinforced IRT distributions on VI were only 0.57 s longer than those on VR (1.015 s on VI vs 0.445 s on VR). Peele et al. attributed their VR–VI rate difference to differences in reinforced IRTs on these schedules. To the extent that pigeons were sensitive to median differences in reinforced IRTs, these results imply pigeons can discriminate between IRTs that differ, on average, by approximately a half second, even though both IRT distributions overlap. Does the literature support such a conclusion?

Data from a study by Shimp (1981) address this question. In this study, Shimp trained pigeons to emit two ranges of IRTs on the center key of a three-key chamber, one that fell within a lower band and the other that fell in a higher band (e.g., IRT class 1.5 to 2 s vs 4.5 to 7 s). Across conditions he varied the size and temporal distance between these bands. Occasionally, a within-band IRT to the center key was followed by illumination of both side keys, one of which was associated with the short IRT class and one of which was associated with the long IRT class. Choice of the key that matched the IRT just emitted on the center key resulted in reinforcement, while choice of the incorrect key did not. Shimp found that as long as the IRT classes differed by more than 1 s, pigeons mastered this conditional discrimination. If, however, the two classes of IRTs were closer to each other than this criterion, accuracy in reporting the prior IRT fell to near-chance levels.

Given Shimp's (1981) finding that segregated distributions of IRTs cannot be reliably discriminated if the IRT bands differ by less than 1 s, we question whether the overlapping reinforced-IRT distributions produced on VR and VI schedules in Peele et al. (1984) that differed, on average, by 0.57 s should be discriminable. The present report tested this thesis in two experiments. In the first experiment, rats had to master what we imagined was an easier problem, discriminating between schedules that reinforced segregated distributions of short IRTs vs long IRTs. To anticipate this experiment's conclusion, rats succeeded in this discrimination. Thereafter, a second experiment was conducted to test whether subjects extended this discrimination to the overlapping reinforced IRTs naturally produced on schedules such as VR and VI.

EXPERIMENT 1: DISCRIMINATION BETWEEN TANDEM RI DRH AND TANDEM RI DRL SCHEDULES

Method

Subjects

Four male Wistar rats, approximately 12 months of age and having a long history of experience on conditional discrimination procedures related to those reported here, served as subjects. They were individually housed in a temperature-controlled vivarium on a 12-hr light/dark cycle where they had continuous access to water, and were occasionally fed to maintain them at 85% of their free-feeding weights.

Apparatus

The experiment was conducted in a chamber with internal dimensions of 21 cm (length) by 28 cm (width) by 27 cm (height). The 21- by 27-cm front and back walls were made of metal. Except for these walls and the metal grid floor, all other surfaces were Plexiglas. In the front wall were two, 4.6-cm wide, retractable levers (comparison levers) that intruded 1.7 cm into the chamber when extended. They were 7.5 cm above the floor, were 12.7 cm apart measured center-to-center, and were equidistant from their proximal side walls. Each lever required a force of approximately 0.15 N to operate. A 2.8-w lamp that produced white light was centered 12 cm above each lever. A 3-cm diameter food cup was centered between the levers, 2 cm above the floor. Centered in the chamber's rear wall was a third lever (sample lever) that was not retractable, located 7.5 cm above the floor. A lamp identical to those in the front wall was centered above this lever, 17.5 cm above the floor.

A ventilation fan masked extraneous sounds. Sound generation was also possible from a buzzer located behind the front wall of the chamber and a white-noise generator. All experimental events and data recording were computer controlled (MED Associates, St. Albans, VT, USA).

Procedure

Subjects were exposed to a trials-based conditional-discrimination procedure adapted from Lattal (1975). Each trial consisted of a sample component presented on the rear-wall lever followed by presentation of two front-wall levers in a choice component.

A sample component began with the presentation of white noise and the illumination of the rear-wall lamp. In the presence of these stimuli, one of two schedules was associated with equal probability with responding on the sample lever: either a tandem random-interval (RI) X-s Differential Reinforcement of High Rate (DRH) 0.5-s schedule or a tandem RI X-s Differential Reinforcement of Low Rate (DRL) Y-s schedule. The schedule associated with the sample lever began operation with the first response to the lever. A response that completed that schedule's contingency ended the sample component. This event was cued by a 0.2-s beep, and ending white noise and illumination of the rear-wall lamp.

Immediately thereafter, the choice component began with the insertion of the two front-wall comparison levers. The stimulus lamp over one lever switched on and off every 0.5 s while the levers were inserted, while the lamp above the second lever was on continuously. A response to either comparison lever resulted in their retraction. If the response was correct, a 0.2-s beep sounded, followed by delivery of a 45-mg food pellet into the food cup and then illumination of the back-wall lamp and the generation of white noise. If, on the other hand, the response was incorrect, a 15-s blackout ensued followed by a correction trial.

In the correction trial, the prior trial type was repeated. If the subject again made an incorrect selection of the comparison lever, the correction trial was repeated a second time. However, upon completion of the schedule on the sample lever, only the correct comparison lever was inserted into the chamber. Sessions lasted for 60 trials, excluding correction trials, and were conducted 5 days per week until 30 sessions had been completed. The assignment of the correct and incorrect to the left and right comparison levers and of constant or blinking lever lights were counterbalanced across subjects.

The 60-trial session was split into six 10-trial blocks. In each block, the value of Y in the tandem RI X-s DRL Y-s was fixed, but it varied as subsequent blocks were chosen in random order and without replacement from among the following six values: 0.1 s, 0.5 s, 0.75 s, 1 s, 1.5 s, and 3 s. For example, in each of the first 10 trials of a 60-trial session, one of two schedules might be associated with the sample lever: Either a tandem RI X-s DRH 0.5-s schedule or, say, a tandem RI X-s DRL 1-s schedule. After 10 trials when these two schedules defined the mixed schedule present on the sample lever, a new tandem RI X-s DRL Y-s schedule would be selected among the five remaining DRL values that may be available. The tandem RI X-s DRH 0.5-s schedule remained the standard schedule against which each of the different tandem RI X-s DRH Y-s schedules was compared. RI schedules were arranged by interrogating a probability gate after every 0.5 s.

During the first session, the value of X in each of the six tandem RI X-s DRH 0.5-s and the six tandem RI X-s DRL Y-s schedules was set to 5. During subsequent sessions, the duration of the tandem RI X-s DRL 3-s schedule, averaged over all prior sessions until five sessions had been completed, was calculated. Thereafter, this calculation was based on a moving average of the last five sessions to this schedule. These calculations of duration of the tandem RI X-s DRL 3-s schedule were divided by the equivalent calculation of duration for each of the six tandem RI X-s DRH 0.5-s schedules and the six tandem RI X-s DRL Y-s schedules. This ratio defined the ratio of increase or decrease in the value of X for the next session.

To illustrate the operation of this procedure, suppose that in the first session the average durations of six sample component RI

X-s DRL Y-s schedules were 5, 10, 15, 20, 25, and 30 s each. In consequence, the next session's X-s values of those six schedules were 5 * 30 / 5 = 30 s, 5 * 30 / 10 = 15 s, 5 * 30 / 15 = 10 s, 5 * 30 / 20 = 7.5 s, 5 * 30 / 25 = 6 s, and 5 * 30 / 30 = 5 s, respectively.

Results

Table 1 presents each tandem schedule that was presented as part of a mixed schedule with tandem RI X-s DRH 0.5-s (compare Schedule 2 with Schedule 1 in the Table) during each of the six 10-trial blocks that composed each session. Also in the table are the median reinforced IRTs that these schedules produced, the time it took to complete them, the proportion of choices between the comparison levers that correctly matched the prior sample-lever tandem schedule, and, finally, the significance of that proportion by a binomial test. Generally speaking, these data show that rats can discriminate between these tandem schedules once the IRT criterion for the DRL terminal link of Schedule 2 reached 0.75 s.

Figure 1 presents the proportion of times each rat correctly reported the schedule type (tandem RI DRL or tandem RI DRH) associated with the sample lever as a function of the absolute median difference in duration between each tandem schedule's terminal-link reinforced IRT (also see Table 1). As is clear from the figure, report accuracy was at above-chance levels no matter what the average difference in reinforced-IRT duration between the two tandem schedules, and tended to improve as the difference increased.

Figure 2 presents the same measure as Figure 1, except that the X-axis variable is the difference in the median duration of operation of the two tandem schedules (Schedule 2 minus Schedule 1 from Table 1) associated with the sample lever. These data show that the difference in duration of these components varied from subject to subject, and from block to block. Nevertheless, most data points cluster around zero, a finding indicating that tandem-schedule durations were often approximately equal. Regardless of the size of difference in duration, all data points are above the Y-axis value of 0.5, a result consistent with the claim that regardless of between-schedule differences in schedule duration, schedule types were discriminated.

This interpretation is buttressed by the data in Figure 3. The top panel of this figure presents the proportion choices of the Schedule-2 lever (choices to the Schedule-2 lever divided by all choices) during the choice component as a function of the duration of the reinforced IRT to the sample lever in the prior sample component. These functions are upward sloping, an outcome consistent with the notion that subjects discriminated the duration of the sample-lever IRT that accessed the choice component. The bottom panel presents the same measure as a function the duration of the sample-lever IRI. These flat functions suggest that sample-lever IRIs played little or no role in facilitating report accuracy in the subsequent choice component.

Figure 4 presents the relative frequency of all IRTs in 0.1-s classes on the sample lever as a function of whether Schedule 1 or Schedule 2 was associated with the lever. The solid line and dashed lines represent Schedules 1 and 2, respectively. As is apparent, these distributions are similar, an outcome consistent with the idea that response emission did not differ with schedule type.

Discussion

The results of the present study demonstrate that tandem RI schedules that have either a DRH or a DRL as their terminal link can be discriminated (see Table 1 and Figures 1, 2 and 3). Further, the finding in Figure 1 that the size of the between-schedule differences in reinforced IRTs is correlated with the size of the conditional discrimination suggests that these between-schedule differences may serve as the basis for this discrimination. Consistent with this view are the data shown in Figure 2 where it appears that another plausible variable controlling schedule discrimination—between-schedule differences in the duration of the two tandem schedules—often appears unrelated to the size of the discrimination attained. Figure 3 supports this interpretation.

Figure 4 addresses a second possibility: Perhaps subjects were sensitive to correlations between different patterns of response emission and completion of the sample-lever schedule. If this were the case, the IRT distributions associated with Schedules 1 and 2 might differ. The results shown in the figure provide no support for this hypothesis.

Table 1

Summary of schedule types and results of Experiment 1.

Rat	Block	Schedule 1	Schedule 2	R-IRT 1 (s)	R-IRT 2 (s)	Duration 1 (s)	Duration 2 (s)	Proportion correct	p-value of binomial test
F1	1	Tand RI X-s	Tand RI X-s DRL 0.1-s	0.21	0.89	30	35	0.57	0.02
	2	DRH 0.5-s	Tand RI X-s DRL 0.5-s	0.22	1.63	28	29	0.70	0.01
	3		Tand RI X-s DRL 0.75-s	0.22	1.67	35	39	0.71	0.01
	4		Tand RI X-s DRL 1-s	0.22	2.05	34	33	0.76	0.01
	5		Tand RI X-s DRL 1.5-s	0.22	2.42	32	38	0.83	0.01
	6		Tand RI X-s DRL 3-s	0.21	3.94	35	49	0.79	0.01
F2	1	Tand RI X-s	Tand RI X-s DRL 0.1-s	0.19	0.46	123	118	0.62	0.01
	2	DRH 0.5-s	Tand RI X-s DRL 0.5-s	0.20	1.26	123	84	0.74	0.01
	3		Tand RI X-s DRL 0.75-s	0.18	1.22	116	142	0.76	0.01
	4		Tand RI X-s DRL 1-s	0.18	1.51	126	122	0.83	0.01
	5		Tand RI X-s DRL 1.5-s	0.18	2.08	113	151	0.84	0.01
	6		Tand RI X-s DRL 3-s	0.18	3.61	118	175	0.86	0.01
F3	1	Tand RI X-s	Tand RI X-s DRL 0.1-s	0.32	1.40	35	30	0.70	0.01
	2	DRH 0.5-s	Tand RI X-s DRL 0.5-s	0.32	1.54	39	27	0.67	0.01
	3		Tand RI X-s DRL 0.75-s	0.29	2.38	42	30	0.79	0.01
	4		Tand RI X-s DRL 1-s	0.31	2.73	42	33	0.77	0.01
	5		Tand RI X-s DRL 1.5-s	0.29	2.94	35	39	0.87	0.01
	6		Tand RI X-s DRL 3-s	0.30	4.03	42	45	0.85	0.01
F4	1	Tand RI X-s	Tand RI X-s DRL 0.1-s	0.26	1.56	44	36	0.55	0.09
	2	DRH 0.5-s	Tand RI X-s DRL 0.5-s	0.28	1.66	36	40	0.55	0.12
	3		Tand RI X-s DRL 0.75-s	0.29	2.77	40	36	0.58	0.01
	4		Tand RI X-s DRL 1-s	0.27	3.37	32	38	0.63	0.01
	5		Tand RI X-s DRL 1.5-s	0.27	3.94	40	42	0.67	0.01
	6		Tand RI X-s DRL 3-s	0.31	4.75	30	36	0.71	0.01

Note: The numerals 1 and 2 in column headers over data denote Schedules 1 and 2, respectively. R-IRT and Duration = 30-session's median of reinforced IRT and IRI duration, respectively, for responses to the back-wall lever. Null hypothesis of binomial test was 0.5.

For five of six blocks, the definition of terminal-link schedule values precluded overlap between each tandem schedule's reinforced IRT distributions. For these blocks, the data in Table 1 show that the between-schedule difference in reinforced IRTs exceeded 1 s. In these regards—non-overlapping reinforced IRT distributions that differ in terms of their medians by 1 s or more—our methods and results duplicate those of Shimp (1981).

While replication of outcome is heartening, replication is not the primary goal of the

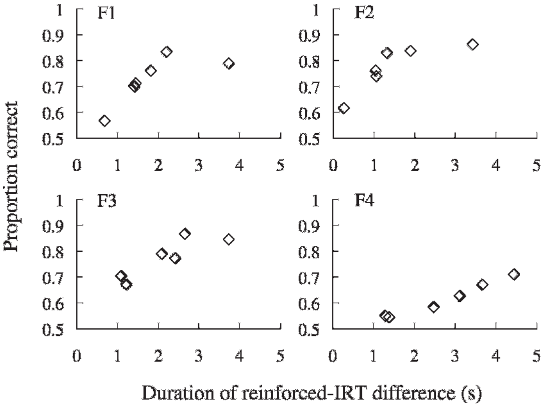

Fig. 1. The proportion of correct choices to the comparison levers as a function of the absolute difference in the reinforced IRTs in s between Schedule 1 and Schedule 2 on the sample lever. Each subject's data are presented in a separate panel.

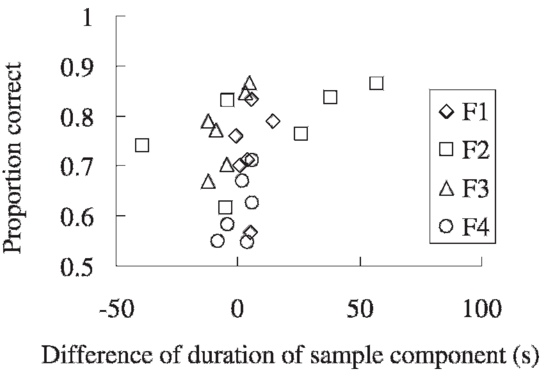

Fig. 2. The proportion of correct choices to the comparison levers as a function of the difference in duration of two types of schedule on the sample lever (Schedule 2 minus Schedule 1).

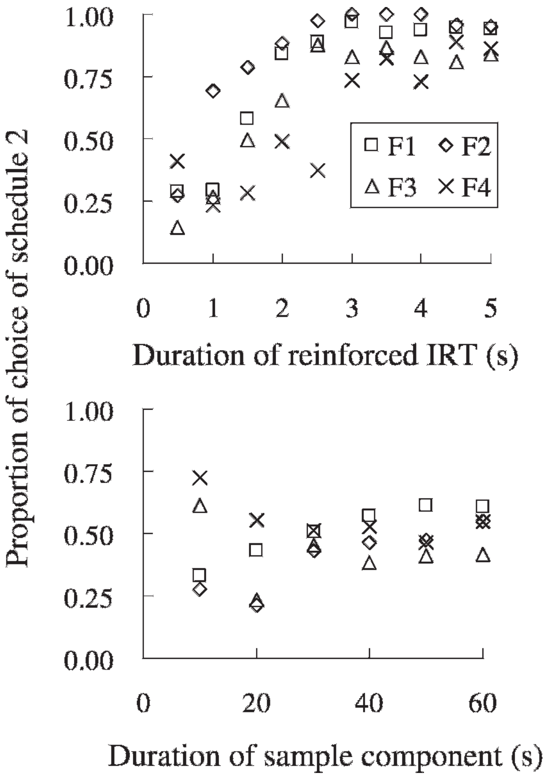

Fig. 3. Proportion of choices to Schedule 2 as a function of the duration of the IRT reinforced on the sample lever (top panel) and as a function of the duration of the IRI (bottom panel). The bin sizes of X-axis are 0.5 s in the top panel and 10 s in the bottom panel.

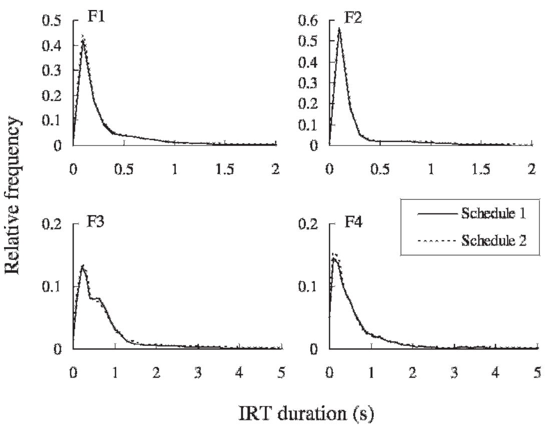

Fig. 4. Relative frequency of an IRT in 0.1-s classes as a function of schedule type.

present work. Instead, the question of interest is whether the overlapping distributions of reinforced IRTs that naturally occur on VR and VI are discriminable. In terms of this question, the results of Block 1 of the experiment, where the mixed schedule on the sample lever was composed of tandem RI DRH 0.5-s and tandem RI DRL 0.1-s schedules, warrant attention. In this block, 3 of 4 subjects discriminated the IRTs reinforced by the two types of tandem schedules even though their distributions overlapped. More impressive, Subject F2 discriminated IRTs even though the median difference between the two tandem schedules was only 0.27 s. No data from Shimp (1981) manifested such a discrimination, possibly because reinforced IRTs in his procedure, unlike those in the present study, were constrained to an interval with an upper and lower bound. In fact, F2's reinforced-IRT discrimination occurred despite being based on smaller differences between reinforced IRTs than those seen to VR and VI schedules from Experiment 1 of Peele et al. (1984). Such a finding suggests that demonstrating a discrimination between the reinforced IRTs generated by a random ratio (RR) and an RI schedule, schedules that are similar to VR and VI, can be realized.

EXPERIMENT 2: DISCRIMINATION OF RI AND TANDEM RI DRL SCHEDULES FROM RR SCHEDULES

Given the successful demonstration of reinforced-IRT discrimination between different tandem schedules in Experiment 1, that experiment's procedure was adapted to a new purpose: comparing ratio against interval schedules. For all trial blocks save one in Experiment 2, rats had to discriminate between the IRTs reinforced on an RR schedule and a tandem RI DRL. Of particular interest was performance during the remaining block, for it would counterpoise RR and RI schedules. Based on those data, it should be possible to determine whether the IRTs naturally reinforced by schedules such as RR and VR are, respectively, distinguishable from those generated on RI and VI schedules.

Method

Subjects

The subjects and their conditions of maintenance were the same as in Experiment 1.

Apparatus

The apparatus was the same as in Experiment 1.

Procedure

The experimental contingencies in use at the end of the prior experiment were altered in two ways. First, the tandem RI X-s DRH 0.5-s schedule was replaced by an RR-Z schedule, which was arranged by interrogating a probability gate after every response; and second, the fifth-block presentation of tandem RI X-s DRL 1.5-s was replaced by an RI X-s schedule. The IRI-yoking scheme from Experiment 1 was adapted to the new mixed schedules associated with the sample lever. For the first session, Z equaled 40, and X equaled 5 for the RI schedule as well as for the five tandem RI X-s DRL Y-s schedules comprising the six blocks in each session (see Table 2; compare Schedules 1 and 2 in the Table). During subsequent sessions, the duration of the tandem RI X-s DRL 3-s schedule was averaged over all prior sessions until five sessions were completed. Thereafter, this calculation was based on a moving average of the last five sessions to this schedule. In both cases, these calculations of duration of the tandem RI X-s DRL 3-s schedule were divided by the equivalent calculation of duration for each of the six tandem RR-Z schedules and the six tandem RI X-s DRL Y-s schedules. This ratio defined the ratio of increase or decrease in the value of Z and X for the next session. In other regards, the procedure was unchanged from that in Experiment 1.

Results and Discussion

Inspection of Table 2, which is organized in the same way as Table 1, shows that in terms of discrimination, only 4 out of 24 block comparisons failed to show a statistically significant discrimination between the block schedule and the comparison schedule, the RR Z. Among the RR, block-schedule comparisons, one is of special interest: that of RR vs RI. For 3 of 4 subjects, discrimination appears to be maintained even based on this mixed schedule (see Block 5 in the table). This result is consistent with the thesis that rats can discriminate between the IRTs naturally reinforced on RR and RI schedules.

Figure 5 plots the proportion of correct choices to the comparison levers as a function of the absolute difference in reinforced IRTs between the RR and all other schedules on the sample lever (Schedule 2 in the table). The closed symbol in each panel presents the results based on comparing the RR against the RI. As noted in Experiment 1, two features of reinforced IRT distributions on VR and VI schedules are that these distributions overlap and that the median difference between these schedules' reinforced IRTs is often less than 1 s (e.g., see Peele et al., 1984). So, while Shimp (1981) has clearly demonstrated that IRTs are discriminable when they come from non-overlapping distributions that differ in average value by amounts in excess of 1 s, there is no evidence prior to that in the present report compatible with the idea that IRT discrimination occurs for the IRT classes naturally reinforced on ratio versus interval schedules. With the data presented in this figure and in Table 2, that evidence is now in hand.

A cautionary note that should be acknowledged is that in this experiment, unlike Experiment 1, there was some tendency for the difference in the durations of the sample-lever component to cluster not over zero, which would indicate that the comparison schedules were of approximately the same duration, but at a positive value—a result indicating that the RR schedule tended to be of shorter duration than its comparison schedule (see Figure 6). This outcome is of some concern because one might argue comparison-lever choice was controlled by this variable and not, as we argue in this report, by differences in the duration of reinforced IRTs (see Figure 4). In our view, there are two reasons not to give this argument credence. First, the experimental design was, except for the inclusion of the RR schedule, largely duplicative of that in Experiment 1. To then argue for control by sample-component duration in Experiment 2, but not Experiment 1, is unparsimonious and ad hoc. And second, the data set of most relevance to our analysis—those that compare RR versus RI component durations (closed squares in Figure 6) provide evidence of discrimination at data points near and on both sides of the value of zero. In consequence, evidence for discrimination remains intact despite the occasional failures at equating component durations seen in Figure 6.

Table 2

Summary of schedule types and results of Experiment.

Rat	Block	Schedule 1	Schedule 2	R-IRT 1 (s)	R-IRT 2 (s)	Duration 1 (s)	Duration 2 (s)	Proportion correct	p-value of binomial test
F1	1	RR Z	Tand RI X-s DRL 0.1-s	0.36	0.66	28	32	0.56	0.08
	2		Tand RI X-s DRL 0.5-s	0.36	1.10	21	32	0.63	0.01
	3		Tand RI X-s DRL 0.75-s	0.36	1.21	27	23	0.66	0.01
	4		Tand RI X-s DRL 1-s	0.40	2.07	19	45	0.71	0.01
	5		RI X-s	0.38	0.63	23	26	0.50	0.95
	6		Tand RI X-s DRL 3-s	0.33	4.42	23	41	0.77	0.01
F2	1	RR Z	Tand RI X-s DRL 0.1-s	0.18	0.27	90	51	0.54	0.14
	2		Tand RI X-s DRL 0.5-s	0.17	1.09	94	86	0.66	0.01
	3		Tand RI X-s DRL 0.75-s	0.18	1.12	96	140	0.68	0.01
	4		Tand RI X-s DRL 1-s	0.18	1.66	86	132	0.66	0.01
	5		RI X-s	0.18	0.55	94	80	0.60	0.01
	6		Tand RI X-s DRL 3-s	0.18	4.21	94	179	0.77	0.01
F3	1	RR Z	Tand RI X-s DRL 0.1-s	0.81	1.15	18	33	0.60	0.01
	2		Tand RI X-s DRL 0.5-s	0.80	1.17	12	21	0.56	0.04
	3		Tand RI X-s DRL 0.75-s	0.70	1.53	18	29	0.69	0.01
	4		Tand RI X-s DRL 1-s	0.76	2.48	18	42	0.67	0.01
	5		RI X-s	0.72	1.38	12	27	0.63	0.01
	6		Tand RI X-s DRL 3-s	0.80	4.40	18	54	0.80	0.01
F4	1	RR Z	Tand RI X-s DRL 0.1-s	0.44	0.79	24	32	0.56	0.04
	2		Tand RI X-s DRL 0.5-s	0.47	1.57	26	44	0.64	0.01
	3		Tand RI X-s DRL 0.75-s	0.44	1.76	24	48	0.54	0.21
	4		Tand RI X-s DRL 1-s	0.41	2.43	24	48	0.71	0.01
	5		RI X-s	0.43	0.87	20	54	0.58	0.01
	6		Tand RI X-s DRL 3-s	0.45	4.78	26	60	0.71	0.01

Note: The numerals 1 and 2 in column headers over data denote Schedules 1 and 2, respectively. R-IRT and Duration = 30-session's median of reinforced IRT and IRI duration, respectively, for responses to the back-wall lever. Null hypothesis of binomial test was 0.5.

Figure 7 presents choice proportions to Schedule 2 as a function of the duration of the sample-lever reinforced IRT. As had been the case in Experiment 1 (see Figure 3), these data support the view that schedule discrimination was based on the duration of reinforced IRTs (see top panel), and not the duration of IRIs (see bottom panel).

Finally, Figure 8 repeats Figure 4's test of the thesis that subjects may have used different patterns of response emission on the sample lever to discriminate schedule types. As had been true for Figure 4, the near identity of the two schedules' functions suggests that response patterning was not the basis for the schedule discriminations seen in this experiment.

GENERAL DISCUSSION

Recently, we endorsed the idea that IRT reinforcement is primarily responsible for the rate differences commonly obtained between VR and VI schedules (Tanno & Sakagami, 2008). An important part of the rationale for this position was that a correlation between response rate and reinforced-IRT duration emerged that was consistent with the primacy of an IRT-reinforcement account. Nevertheless, inspection of Table 1 from Tanno and

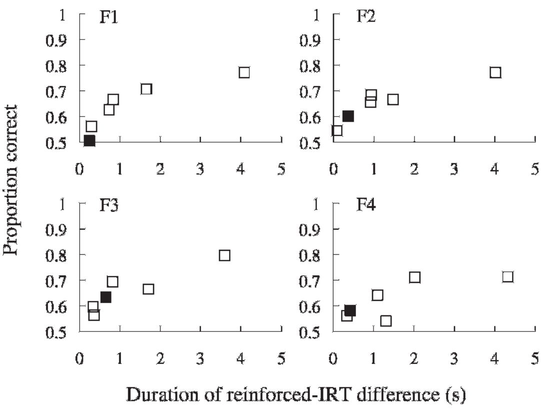

Fig. 5. The proportion of correct choices to the comparison levers as a function of the absolute difference in the reinforced IRTs in s between Schedule 1 and Schedule 2 on the sample lever for each of 4 rats. The closed-box points present data from Block 5, where the comparison was between RI and RR schedules.

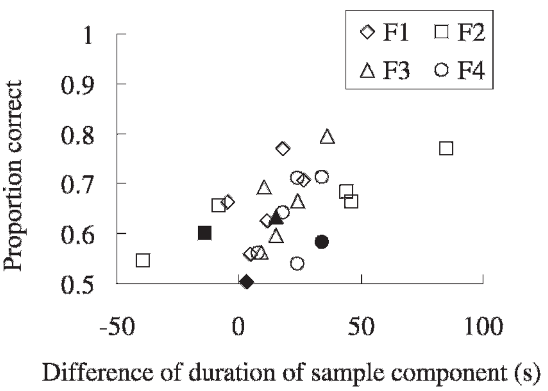

Fig. 6. The proportion of correct choices to the comparison levers as a function of the difference in duration of two types of schedule on the sample lever (Schedule 2 minus Schedule 1). The closed points present data from Block 5, where the comparison was between RI and RR schedules.

Sakagami (2008) had one perplexing aspect: the median reinforced IRT on VI was sometimes only a fraction of a second longer than when the alternate schedule to which it was compared was a VR. Given that Shimp (1981) found that such small differences in reinforced IRTs are difficult for a pigeon to discriminate, we adapted his procedure to a new test that addressed the following question: Can rats discriminate between the IRTs naturally reinforced by VR and VI schedules? The results from this report suggest that they can.

In Tanno and Sakagami (2008), rate control by IRT reinforcement was counterpoised against an account based on the reinforcement-feedback function between response rate and reinforcement rate (Baum, 1981). According to Baum's account, rates are higher to ratio schedules than to interval schedules not because of between-schedule differences in reinforced IRTs, but because, at the margin, increases in response rate are more productive of additional reinforcement on ratio schedules.

The results of the present report support Tanno and Sakagami (2008) in arguing for the primacy of an IRT-reinforcement account of the ratio-interval, response-rate difference. This support takes two forms, the more obvious of which is the fact that changes in IRT reinforcement correlated with changes in response rate. But also of note should be the difficulty of Baum's (1981) account in accommodating results from a procedure such as ours.

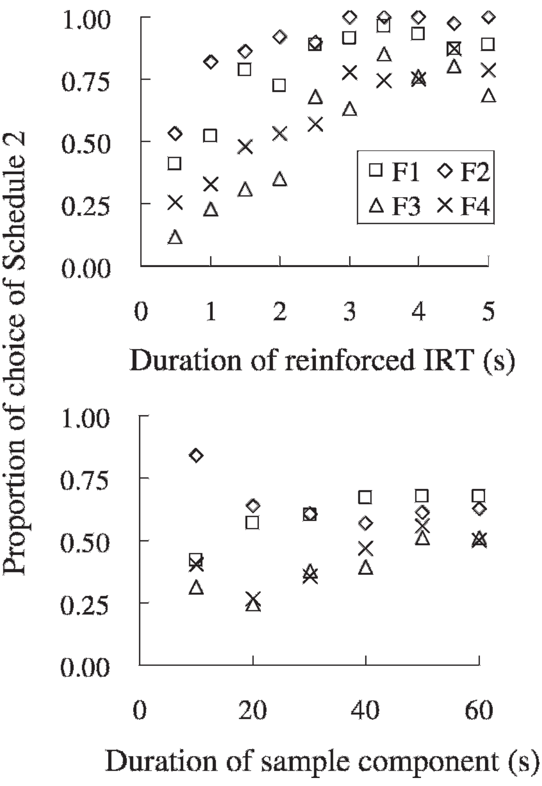

Fig. 7. Proportion of choices to Schedule 2 as a function of the duration of the IRT reinforced on the sample lever (top panel) and as a function of the duration of the IRI (bottom panel). The bin sizes of X-axis are 0.5 s in the top panel and 10 s in bottom panel.

In the standard application of Baum's (1981) account, it is hypothesized that rate differentiation between schedule types is due to between-schedule differences in the temporal flow of reinforcement induced by changes in response rate. For example, in Tanno and Sakagami (2008), rats were exposed to 40 successive IRIs before session's end. Presumably, variations in response rates within a schedule produced different variations in reinforcement rates depending on whether the reinforcement schedule was interval or ratio based. Over these many reinforcements, the opportunity to discern response-rate, reinforcer-rate correlations would seem to be present. The design of the present work differs from Tanno and Sakagami and all other IRT-reinforcement studies of which we are aware except for Shimp (1981), in that the opportunity for assessing response-rate–reinforcer-rate correlations was reduced to exposure to a single IRI on the sample lever. Because of this

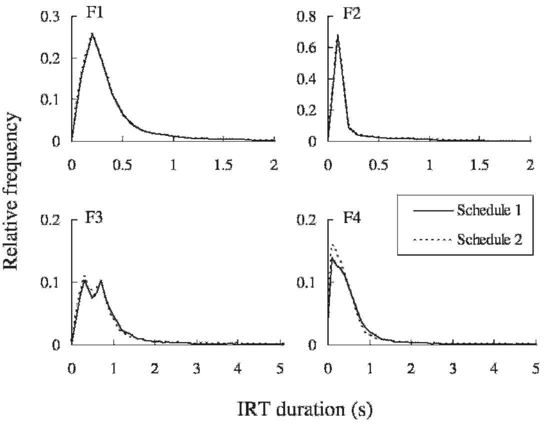

Fig. 8. Relative frequency of an IRT in 0.1-s classes as a function of schedule type.

fact, we find it is difficult to conceive that the schedule discriminations between RR and RI evidenced by 3 of 4 rats in Experiment 2 could have been a consequence of the operation of the IRI as a controlling variable because the opportunity to assess correlations between reinforcer rate and response rate was meager, indeed. In this regard, the present work complements the conclusions of Tanno and Sakagami in supporting an account of the VR–VI rate difference based on IRT reinforcement.

The results of the present report show that rats can discriminate between the IRTs naturally reinforced by ratio and interval schedules. A plausible application of this demonstration to theory is that between-schedule differences in IRT reinforcement are the reason that interval-schedule response rates lag those seen on ratio schedules. Plausible though such an application might be, its validity is not assured.

Many tests of the role played by IRT reinforcement in producing the VR–VI rate difference compare response rates on tandem schedules in which the initial link is either a VR or a VI and the terminal link involves some IRT-reinforcement schedule such as DRH or DRL (e.g., see Peele et al., 1984; Tanno & Sakagami, 2008). With this arrangement, it is possible to have animals respond on ratio or interval schedules that have reinforced IRTs of specified duration. If the reinforced IRTs and response rates between a ratio-based and an interval-based tandem schedule are, as a consequence, approximately equal, the attribution is made that the response-rate equation is due to equation of reinforced IRTs.

While this claim is correct, it may not be of relevance to explaining the VR–VI rate difference. The problem is that rate equation may be the result of rate shaping through IRT reinforcement. That is, because the experimenter requires a criterion IRT for reinforcement, that IRT is shaped by the schedule, and the rate equation that follows is little more than an epiphenomenal correlate of this rate-shaping exercise. The rats in the present report have demonstrated they can discriminate reinforced IRTs. Should it surprise, then, that were a procedure devised akin to those of Peele et al. (1984) or Tanno and Sakagami (2008), these rats would be capable of emitting the IRTs they can discriminate, producing rate equation between tandem schedules whose initial links are VR versus VI (also see Silberberg, Goto, Hachiga, & Tanno, 2008)?

Data supportive of skepticism concerning the relevance of IRT-reinforcement tests such as those of Peele et al. (1984) and others comes from Shull, Gaynor, and Grimes (2001). They argue that response-rate changes are due to changes in two variables: the likelihood that an animal will begin a response bout, and the duration of that bout. In their comparison of VR and VI schedules, they note an important between-schedule difference in manipulations of schedule parameters. Increasing the VI reinforcement rate tends to increase the rate of initiating a response bout, but not its duration. On the other hand, creating a tandem VI VR from a simple VI schedule tends to increase the duration of a bout, but not its rate of initiation. In both cases, response rates increase, but the increases are due to the operation of different components of a response-rate composite. Results such as these raise the possibility that rate equation between VR and VI schedules produced through reinforced-IRT equation may not serve as the only basis for explaining why these schedules support different response rates.

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